Hoyle's Tornado Origin of Artificial Life: A Computer Programming Challenge

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The origin of life is one of the outstanding conundrums of modern biology, which has been tackled mostly from a chemical point of view. It is also the playground of creationists who use probability arguments to deny that life could ever have begun "at random". The latter (Babuna, 2008; Gotfryd, 2008; Gündogdu, 2008) especially like to quote scientists who express doubt, such as:

> "In a popular lecture I once unflatteringly described the thinking of these scientists as a 'junkyard mentality'. Since this reference became widely and not quite accurately quoted I will repeat it here. A junkyard contains all the bits and pieces of a Boeing 747, dismembered and in disarray. A whirlwind happens to blow through the yard. What is the chance that after its passage a fully assembled 747, ready to fly, will be found standing there? So small as to be negligible, even if a tornado were to blow through enough junkyards to fill the whole Universe" (Hoyle, 1984).

I would like to suggest that artificial life (Alife) enthusiasts take up Fred Hoyle's challenge, that in a way they simulate a tornado going through a junkyard of parts, and come up with something we would all agree is alive, in the Alife sense, from components that are not alive in the Alife sense (Pennock, 2001; Pennock, 2007).

What is needed is the statistical mechanics approach of the ensemble (Hill, 1960), a large number of "identical" systems, each simulating its own tornado and junkyard of parts. Given the power of modern parallel computation, the size of the ensemble could be considerable. All we need is for one member of the ensemble to make the transition from non-Alife to Alife to prove the point. Thus I am suggesting that Alife enthusiasts have an opportunity to solve the "Origin of Artificial Life" problem well before the chemists will solve the "Origin of Life" problem. By the Strong Alife Hypothesis (Levy, 1992; Boden, 1996; Olson, 1997; Anderson & Copeland, 2002), in which Alife is considered a realization of life, Alife enthusiasts will also have solved the latter problem.

Let's now try to get a handle on the magnitude of the problem. Everyone seems to be willing to have the junkyard already full of scraps that resemble parts of organisms, that are strong enough not to be pulverized by tornados. We don't have to simulate the Big Bang or the condensation of atoms or even the nucleosynthesis of the heavier "metals" (as the astronomers call all atoms more massive than helium.) We might even be allowed some pretty complex organic molecules, as these are now found in abundance in the universe, and presumed to be abiotic (Gordon & Hoover, 2007). Abiotic capsules, which might isolate components into an ensemble of junkyards, might even be permitted by the nay-sayers (Fox, 1965, 1972; Brooke & Fox, 1977; Fox, 1980, 1980; Luisi, Stano, Rasi, et al., 2004). So, taking the assembly problem as the goal, let us assume that capsule j in an ensemble of N capsules has n_{ij} copies of $i = 1,\ldots,C_j$ components, each not Alife alive, but that some subset of their arrangements within the capsule meets the criterion of being "Alife alive". In the acceptance of the tornado and junkyard paradigm for the origin of life, creationists have already conceded a materialistic interpretation of at least primitive life in putting forth their improbability arguments, so the only question is one of combinatorics. Combinatorics are more constrained the smaller the volume of a capsule, so the concept of the crowded cytoplasm (Fulton, 1982; Berg, 1990; Han & Herzfeld, 1993; Garner & Burg, 1994; Murphy & Zimmerman, 1994; Lindner & Ralston, 1997; Minsky, Ghirlando & Reich, 1997; Jaenicke, 1998; Rohwer, Postma, Kholodenko, et al., 1998; Burg, 2000; Ellis, 2001, 2001; Kinjo & Takada, 2002; Bernado, Garcia de la Torre & Pons, 2004; Ovadi & Saks, 2004; Tokuriki, Kinjo, Negi, et al., 2004; Weiss, Elsner, Kartberg, et al., 2004) may actually enhance the probability of some capsule making the transition from non-Alife to Alife.

Given an origin of the universe 13.7 x 10^9 years ago, and firm evidence for life on earth at 3.8 x 10^9 years ago, real life could have originated any time between 10^6 ABB (years After the Big Bang) to (13.7-3.8) x $10^9 \approx 10^{10}$ ABB. That is time enough for many tornados. So we're not talking about one tornado in one junkyard, but quite a plethora of consecutive tornados in each of a rather large ensemble of capsules. At 10^{11} stars in our galaxy and 10^{11} galaxies in the visible universe (Gordon & Hoover, 2007), half of which may have planets, and a froth of capsules say 200 nm in radius, to correspond to the smallest known cell (Huber, Hohn, Rachel, et al., 2002; Waters, Hohn, Ahel, et al., 2003), in a monolayer on half the surface just one planet per solar system of radius 5000 km, we get 10^{27} capsules per solar system. This comes to 10^{49} capsules in the known universe. That's a rather large ensemble of capsules within which the transition of life could have occurred in a few. The limit on an Alife approach is really on how many capsules and tornados we can simulate with present day computers, and whether that will be enough to solve the Origin of Alife Problem.

In a limited way, the problem has already been solved in the affirmative. In *The Game of Life* (Gardner, 1970; Pennock, 2001; Beer, 2004) a random starting condition will often produce gliders and other "self-reproducing" patterns. Another example is the spontaneous formation of patterns from subsets of random sequences of RNAs, such as palindromes (Guo, 2005). This suggests a way to achieve modularity in the tornado assembly process. In an RNA palindrome, the binding between complementary portions of an RNA strand can serve to hold it together when a tornado comes through, compared to nonpalindromic portions of the sequence. Thus, in a world of irreversible processes, a bias could occur favoring sequences that produce bigger, more complex structures. Given the enzymatic nature of RNA, and the baby steps that have been taken towards its possible self-replication, we can start to see how the Origin of Alife might be programmed. Experiments on the directed selection of RNA already select out quite rare specific RNA sequences:

> "SELEX (systematic evolution of ligands by exponential enrichment) has proven to be an excellent tool for finding nucleotide molecules that have a high affinity for a particular target from a random pool under specific conditions. It involves three processes, namely: selection of ligand sequences that bind to a target; partitioning of aptamers from non-aptamers via affinity methods; and amplification of bound aptamers…. The most successful aptamers selected by SELEX represent 1 in 10^9 to 1 in 10^{13} of the molecules in the starting library" (Gopinath, 2007).

Suppose only one in 10^{13} capsules made the transition from non-life to life. Life would then have started $10^{49}/10^{13} = 10^{46}$ times in the known universe, i.e., much more frequently than the 5 x 10^4 minimum starts necessary to populate the whole universe (Gordon & Hoover, 2007). With each of the 10^{49} capsules experiencing just one tornado per year to rearrange its parts, with 10^{10} years available the universe could have 10^{59} opportunities to start life. However, diffusion within a capsule will rearrange its components roughly every 0.1 sec, based on a diffusion coefficient of about 10 μm^2/sec (Mullineaux, Nenninger, Ray, et al., 2006), raising the number of tornados by a factor of 3 x 10^6, or about 10^{65} opportunities to start life. The nays may not have it.

To summarize, the challenge to the Alife enthusiast in trying to solve the Problem of the Origin of Alife seems to be roughly the following:

1) Choose a criterion for distinguishing non-Alife parts from “live” Alife organisms.
2) By hand or simulated evolution, construct at least one Alife organism from non-Alife parts that you deem alive by your criterion, so we know the goal is attainable. You have acted as the Intelligent Designer in this case (Gordon, 2000).
3) Place random mixtures of these parts into a very large ensemble of capsules.
4) Let the parts interact in a partially irreversible fashion, i.e., simulate a system that is not at thermodynamic equilibrium. This should allow some modularity to form.
5) Simulation of an energy source and sink could create a physics with gradients and fluxes that provide some asymmetry within a capsule. For example, compactness of parts could be interpreted as varying density, resulting in gravitational stratification or electrophoretic separation (Jaffe, 1969; Dante, Michalik, Mathew, et al., 1995).
6) Let the modules interact in a higher order fashion, such as steric hindrance (no overlapping), sticking together if they are “complementary”, knot formation, etc.
7) Run simulation of the ensemble of capsules for a long time.
8) See if your hand constructed Alife organism arises out of this ensemble of capsules, or perhaps something else that meets your criterion of being live Alife, that you didn’t anticipate.

Note that I have not constrained the parts to be similar to real molecules. Thus discussions of what kind of physics to simulate, of the parts or their environment, is left open to the programmer’s imagination, without constraints to make Alife look like real life, such as:

> “The environment may be deéned either by natural geochemistry or artificially, but should involve only simple forms of energy and material, so that the goal is to create an encapsulated biochemical system that can derive energy from simple chemicals or light (a simple form of metabolism, e.g. by redox coupling) and use information carried in primitive genes. This proto-organism, which may be held together by a lipid aggregate, should be able to self-replicate, use energy and nutrients from its environment, undergo evolutionary changes over time, and die” (Bedau, McCaskill, Packard, et al., 2000).

One can adjust the guesstimates above in many ways. The bottom line is that the number of opportunities for a spontaneous origin of life is huge, that creationists have accepted that simple life is materialistically based and thus just improbable in their eyes, but that the number of opportunities might indeed exceed the constraints of the combinatorics. Turning the above pseudocode into a convincing simulation of the Origin of Alife will be a lot of work, but it could produce a major advance in our understanding of the Origin of Real Life.

References

Anderson, D. & B.J. Copeland (2002). Artificial life and the Chinese room argument. *Artif Life* **8**(4), 371-378.

Babuna, O. (2008). The origin and creation of life. In: *Divine Action and Natural Selection: Questions of Science and Faith in Biological Evolution [in press]*. Seckbach, J. and R. Gordon. Singapore, World Scientific.

Bedau, M.A., J.S. McCaskill, N.H. Packard, S. Rasmussen, C. Adami, D.G. Green, T. Ikegami, K. Kaneko & T.S. Ray (2000). Open problems in artificial life. *Artificial Life* **6**(4), 363-376.

Beer, R.D. (2004). Autopoiesis and cognition in the game of life. *Artif Life* **10**(3), 309-326.

Berg, O.G. (1990). The influence of macromolecular crowding on thermodynamic activity: solubility and dimerization constants for spherical and dumbbell-shaped molecules in a hard-sphere mixture. *Biopolymers* **30**(11-12), 1027-1037.

Bernado, P., J. Garcia de la Torre & M. Pons (2004). Macromolecular crowding in biological systems: hydrodynamics and NMR methods. *J Mol Recognit* **17**(5), 397-407.

Boden, M.A. (1996). *The Philosophy of Artificial Life*. Oxford, Oxford University Press.

Brooke, S. & S.W. Fox (1977). Compartmentalization in proteinoid microspheres. *Biosystems* **9**(1), 1-22.

Burg, M.B. (2000). Macromolecular crowding as a cell volume sensor. *Cell Physiol Biochem* **10**(5-6), 251-256.

Dante, M., S.S. Michalik, Z. Mathew, B. Doray, L.L. Ho, K.J. Wise & T.W. Christianson (1995). Retardation of RNA electrophoretic mobility due to a palindromic region. *Anal Biochem* **225**(2), 348-351.

Ellis, R.J. (2001). Macromolecular crowding: obvious but underappreciated. *Trends Biochem Sci* **26**(10), 597-604.

Ellis, R.J. (2001). Macromolecular crowding: an important but neglected aspect of the intracellular environment. *Curr Opin Struct Biol* **11**(1), 114-119.

Fox, S.W. (1965). *The Origins of Prebiological Systems and of Their Molecular Matrices*. New York, Academic Press.

Fox, S.W. (1972). *Molecular Evolution and the Origin of Life*. San Francisco, W.H.Freeman & Co.

Fox, S.W. (1980). Life from an orderly cosmos. *Naturwissenschaften* **67**(12), 576-581.

Fox, S.W. (1980). Metabolic microspheres: origins and evolution. *Naturwissenschaften* **67**(8), 378-383.

Fulton, A.B. (1982). How crowded is the cytoplasm? *Cell* **30**, 345-347.

Gardner, M. (1970). Mathematical games, The fantastic combinations of John Conway's new solitaire game "life". *Sci. Amer.* **223**(4), 120-123.

Garner, M.M. & M.B. Burg (1994). Macromolecular crowding and confinement in cells exposed to hypertonicity. *Am J Physiol* **266**(4 Pt 1), C877-892.

Gopinath, S.C.B. (2007). Methods developed for SELEX. *Analytical and Bioanalytical Chemistry* **387**(1), 171-182.

Gordon, R. (2000). The emergence of emergence: a critique of "Design, observation, surprise!". *Rivista di Biologia /Biology Forum* **93**(2), 349-356.

Gordon, R. & R.B. Hoover (2007). Could there have been a single origin of life in a big bang universe? *Proc. SPIE* **6694**, doi:10.1117/1112.737041.

Gotfryd, A. (2008). Evolution: myths and facts. In: *Divine Action and Natural Selection: Questions of Science and Faith in Biological Evolution [in press]*. Seckbach, J. and R. Gordon. Singapore, World Scientific.

Gündogdu, C. (2008). The collapse of the theory of evolution. In: *Divine Action and Natural Selection: Questions of Science and Faith in Biological Evolution [in press]*. Seckbach, J. and R. Gordon. Singapore, World Scientific.

Guo, P. (2005). RNA nanotechnology: engineering, assembly and applications in detection, gene delivery and therapy. *J Nanosci Nanotechnol* **5**(12), 1964-1982.

Han, J. & J. Herzfeld (1993). Macromolecular diffusion in crowded solutions. *Biophys J* **65**(3), 1155-1161.

Hill, T.L. (1960). *An Introduction to Statistical Thermodynamics*. Reading, Addison-Wesley Publishing Co.

Hoyle, F. (1984). *The Intelligent Universe*. New York, Holt Rinehart and Winston.
Huber, H., M.J. Hohn, R. Rachel, T. Fuchs, V.C. Wimmer & K.O. Stetter (2002). A new phylum of Archaea represented by a nanosized hyperthermophilic symbiont. *Nature* **417**(6884), 63-67.
Jaenicke, R. (1998). Protein self-organization in vitro and in vivo: partitioning between physical biochemistry and cell biology. *Biol Chem* **379**(3), 237-243.
Jaffe, L.F. (1969). On the centripetal course of development, the Fucus egg, and self-electrophoresis. *Dev. Biol.* **3**(Suppl.), 83-111.
Kinjo, A.R. & S. Takada (2002). Effects of macromolecular crowding on protein folding and aggregation studied by density functional theory: dynamics. *Phys Rev E Stat Nonlin Soft Matter Phys* **66**(5 Pt 1), 051902.
Levy, S. (1992). *Artificial Life, The Quest for a New Creation*. New York, Pantheon Books.
Lindner, R.A. & G.B. Ralston (1997). Macromolecular crowding: effects on actin polymerisation. *Biophys Chem* **66**(1), 57-66.
Luisi, P.L., P. Stano, S. Rasi & F. Mavelli (2004). A possible route to prebiotic vesicle reproduction. *Artificial Life* **10**(3), 297-308.
Minsky, A., R. Ghirlando & Z. Reich (1997). Nucleosomes: a solution to a crowded intracellular environment? *J Theor Biol* **188**(3), 379-385.
Mullineaux, C.W., A. Nenninger, N. Ray & C. Robinson (2006). Diffusion of green fluorescent protein in three cell environments in *Escherichia coli*. *J Bacteriol* **188**(10), 3442-3448.
Murphy, L.D. & S.B. Zimmerman (1994). Macromolecular crowding effects on the interaction of DNA with Escherichia coli DNA-binding proteins: a model for bacterial nucleoid stabilization. *Biochim Biophys Acta* **1219**(2), 277-284.
Olson, E.T. (1997). The ontological basis of strong artificial life. *Artif Life* **3**(1), 29-39.
Ovadi, J. & V. Saks (2004). On the origin of intracellular compartmentation and organized metabolic systems. *Mol Cell Biochem* **256-257**(1-2), 5-12.
Pennock, R.T. (2001). Getting A-Life: negotiating the border between virtual and real. In: *International Society for the History, Philosophy and Social Studies of Biology Meeting, 18-22 July 2001 at Quinnipiac University in Hamden, Connecticut*.
Pennock, R.T. (2007). Models, simulations, instantiations, and evidence: the case of digital evolution. *Journal of Experimental & Theoretical Artificial Intelligence* **19**(1), 29-42.
Rohwer, J.M., P.W. Postma, B.N. Kholodenko & H.V. Westerhoff (1998). Implications of macromolecular crowding for signal transduction and metabolite channeling. *Proc Natl Acad Sci USA* **95**(18), 10547-10552.
Tokuriki, N., M. Kinjo, S. Negi, M. Hoshino, Y. Goto, I. Urabe & T. Yomo (2004). Protein folding by the effects of macromolecular crowding. *Protein Sci* **13**(1), 125-133.
Waters, E., M.J. Hohn, I. Ahel, D.E. Graham, M.D. Adams, M. Barnstead, K.Y. Beeson, L. Bibbs, R. Bolanos, M. Keller, K. Kretz, X. Lin, E. Mathur, J. Ni, M. Podar, T. Richardson, G.G. Sutton, M. Simon, D. Soll, K.O. Stetter, J.M. Short & M. Noordewier (2003). The genome of *Nanoarchaeum equitans*: insights into early archaeal evolution and derived parasitism. *Proc Natl Acad Sci U S A* **100**(22), 12984-12988.
Weiss, M., M. Elsner, F. Kartberg & T. Nilsson (2004). Anomalous subdiffusion is a measure for cytoplasmic crowding in living cells. *Biophys J* **87**(5), 3518-3524.